Beam Diagnostics for NDCX-II

Steve Lidia

2010 HIF-VNL Program Advisory Committee Meeting

Livermore, CA

8-9 December 2010

Outline

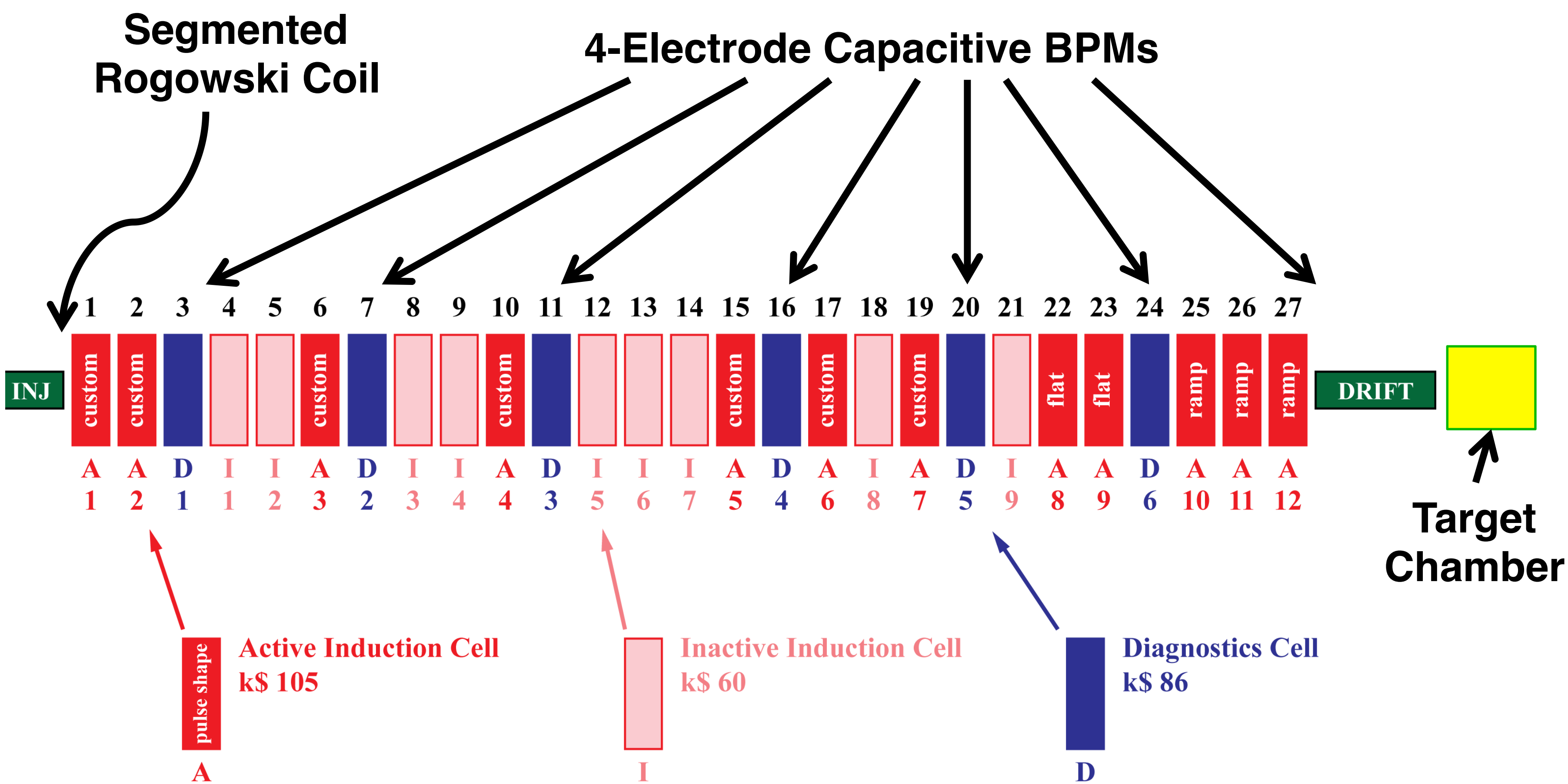
NDCX-II beamline
- **Diagnostic stations**
- **Beam parameter evolution**
- **Beamline element diagnostics**

Baseline beam diagnostics
- **Injector**
- **Accelerator**
- **Target Chamber**

Measuring Beam Fluence and Intensity on Target

Non-Baseline and Future Diagnostic Development

NDCX-II April 2010 Baseline Configuration



Beamline element diagnostics for machine performance and machine protection

- **Solenoids**
  - Current monitoring transformer (*Pearson 1423*)
- **Dipole Corrector**
  - Current monitoring transformer (*Pearson 5046*)
- **Injector and Accelerator**
  - Low-voltage, long pulse: Calibrated resistive voltage monitor
  - High-voltage, short pulse: ATA capacitive voltage monitors (<70ns risetime)
  - Pulse Sciences Liquid Resistive Voltage Monitor will be utilized for calibration
- **FEPS Plasma**
  - Resistive voltage divider (essential to diagnose dielectric failure)
  - Current monitoring transformer (*Ion Physics CM-1-M*)
- **FCAPS Plasma**
  - Current monitoring transformer (*Pearson 410*)

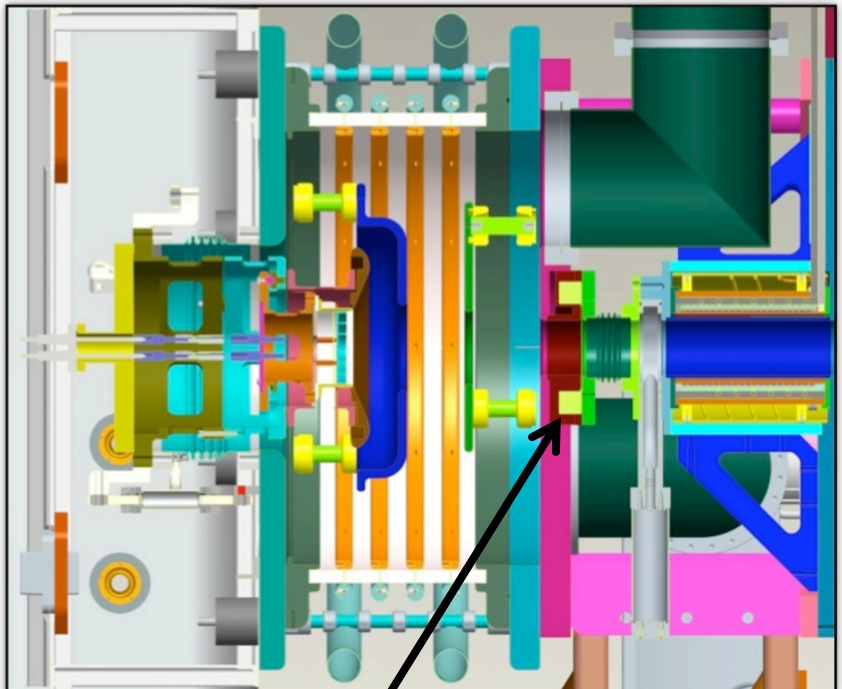
Diagnostic signals will be captured and archived for every shot

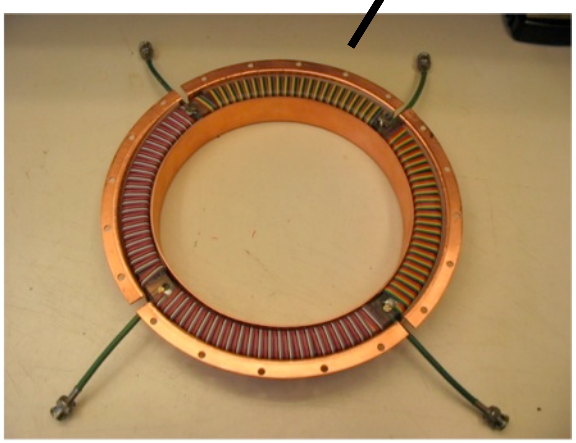
Beam diagnostics must effectively measure beam parameters that vary over 2 orders of magnitude.

Lattice Period #	Distance from source (m)	Average kinetic energy (keV)	Pulse duration, FWHM (ns)	Peak Current (A)	Peak line charge (nC/m)
3	1.28	150	600	0.10	50
7	2.40	172	500	0.13	62
11	3.52	193	300	0.18	86
16	4.92	222	120	0.36	153
20	6.04	294	40	0.96	346
24	8.28	682	32	0.86	186
Linac exit	9.12	1252	15.5	1.46	253
Target plane	10.05	1239	1	12.73	2206

~ 1/500 ~120 ~ 40

Prototype injector segmented Rogowski coil has been tested on the bench into an active integrator and differential amplifier

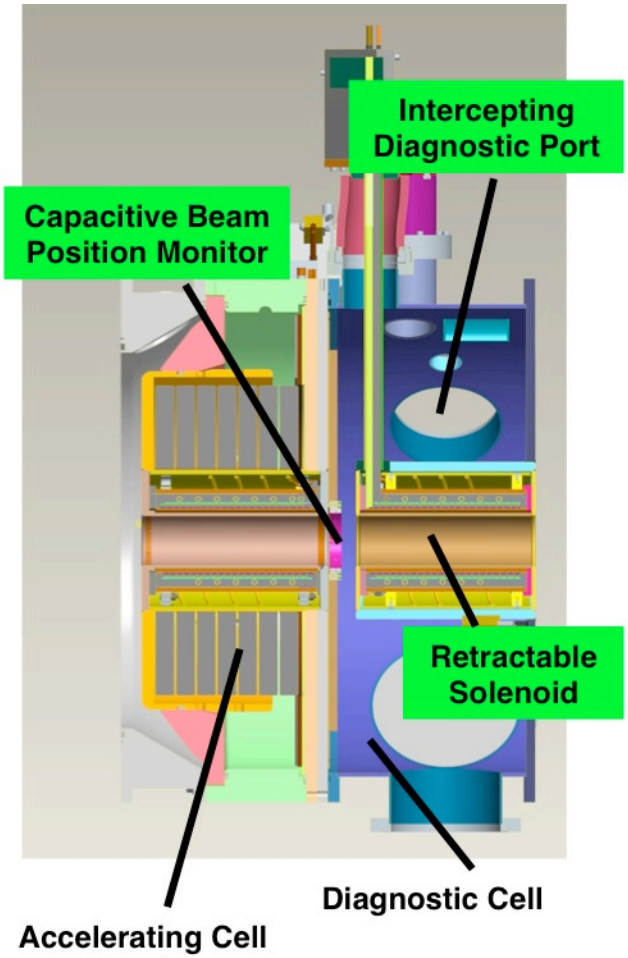




10-inch mean diameter

- Tests done with 100mA, 1us pulse, 20ns risetime
- Results scaled to slower NDCX-II injector dI/dt = 80mA/200ns
- Resolution of ~1mm (without potential NDCX-II noise)
- Risetime limit of <70ns
- Rogowski coil signal generated by the injector solenoid will have to be subtracted

Accelerator beam diagnostic cells provide suite of beam measurements



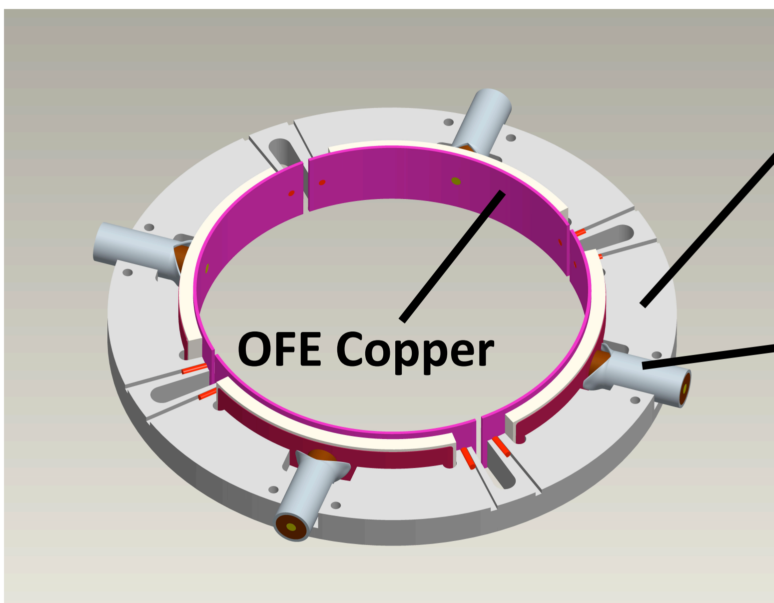
Beam Parameter	Measurement Method	Intercepting?
Beam Energy	Time of Flight Voltage Summation	No No
Bunch Charge	Faraday Cup Capacitive Probe	Yes No
Pulse Duration	Faraday Cup Capacitive Probe	Yes No
Transverse Centroid Offset	Capacitive BPM Slit Cup Scintillator	No Yes Yes
Transverse Phase Space & Profile	Slit/Scintillator Slit/Slit-Cup	Yes Yes
Target Plane Fluence	Faraday Cup/Cap. Probe + Scintillator/Calorimeter	Yes

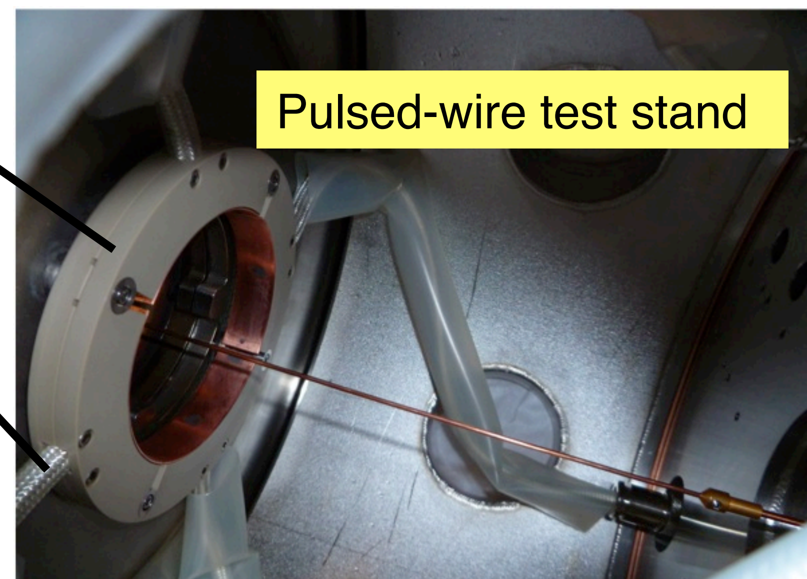
Capacitive beam position monitor will be the primary non-interceptive beam diagnostic

We adopt a 4-electrode capacitive probe to measure the beam temporal charge profile and transverse offset.

The BPM is constructed from a vacuum compatible thermoplastic, PEEK, with OFE copper electrodes.

Signal plate inner radius	**4.17 cm**
Insulator radial thickness	**1 mm**
PEEK dielectric @ 1MHz	**3.3**
Electrode length	**1.27 cm**
Capacitance to ground	**~25 pF**
Z_{line}	**50 Ω**
RC	**~1ns**





WARP models have benchmarked predicted BPM response and sensitivity thresholds

NDCX-II machine model with random solenoid head and tail offsets (randomly picked from a uniform distribution spanning ±0.5mm)

Bench tests of BPM response validate the simple circuit model (RC ~1ns).

Gap	Voltage sum Range (V)	[d(λbeam)/dt] (C/m-s) Range
3	0.7	1.7
7	0.8	1.9
11	1.5	2.4
16	4.0	6.2
20	27	43
24	39	61
28	118	185

Gap	DX/x (V/mm)	DY/y (V/mm)	20mV threshold (mm)
3	1.20E-02	7.30E-03	2.1E+00
7	8.89E-04	4.07E-03	8.1E+00
11	2.61E[illegible]	[illegible]	5.6E-01
16	4.00E[illegible]	[illegible]	4.2E-01
20	2.25E[illegible]	[illegible]	5.3E-02
24	1.66E[illegible]	[illegible]	6.0E-02
28	4.37E-01	4.99E-01	4.3E-02

Amplification may be required at early stages to increase sensitivity

Movable diagnostic box for in-situ beam distribution and emittance measurements

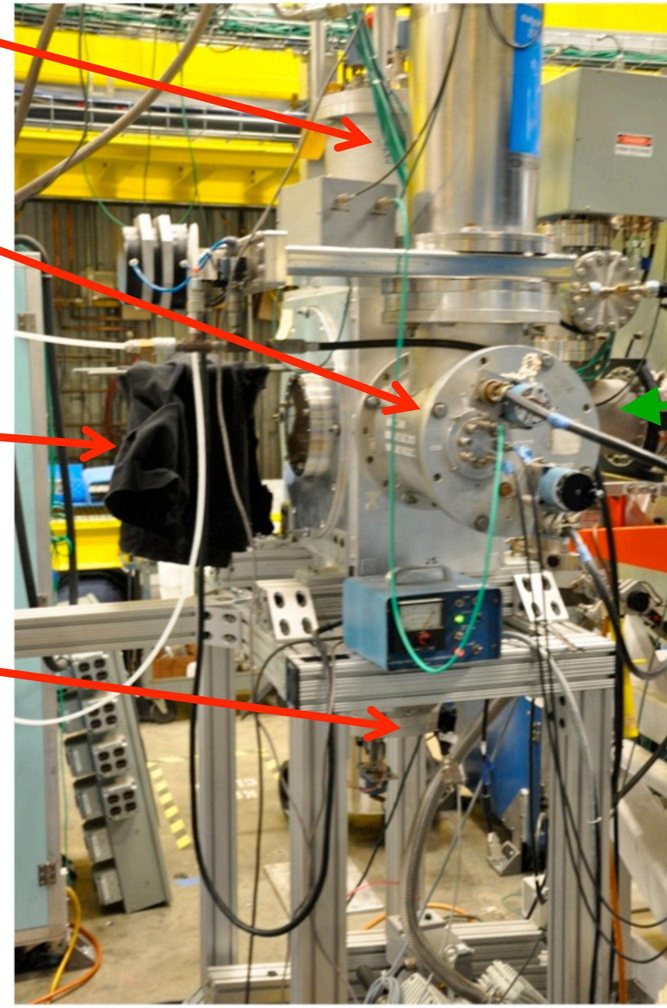
Vertical slit and slit-cup

Horizontal slit and slit-cup

Gated, Fast MCP Camera mount

Deep Faraday cup and scintillator

Side-mounted scintillator drive and camera mount will allow insertion into the NDCX-II beamline.

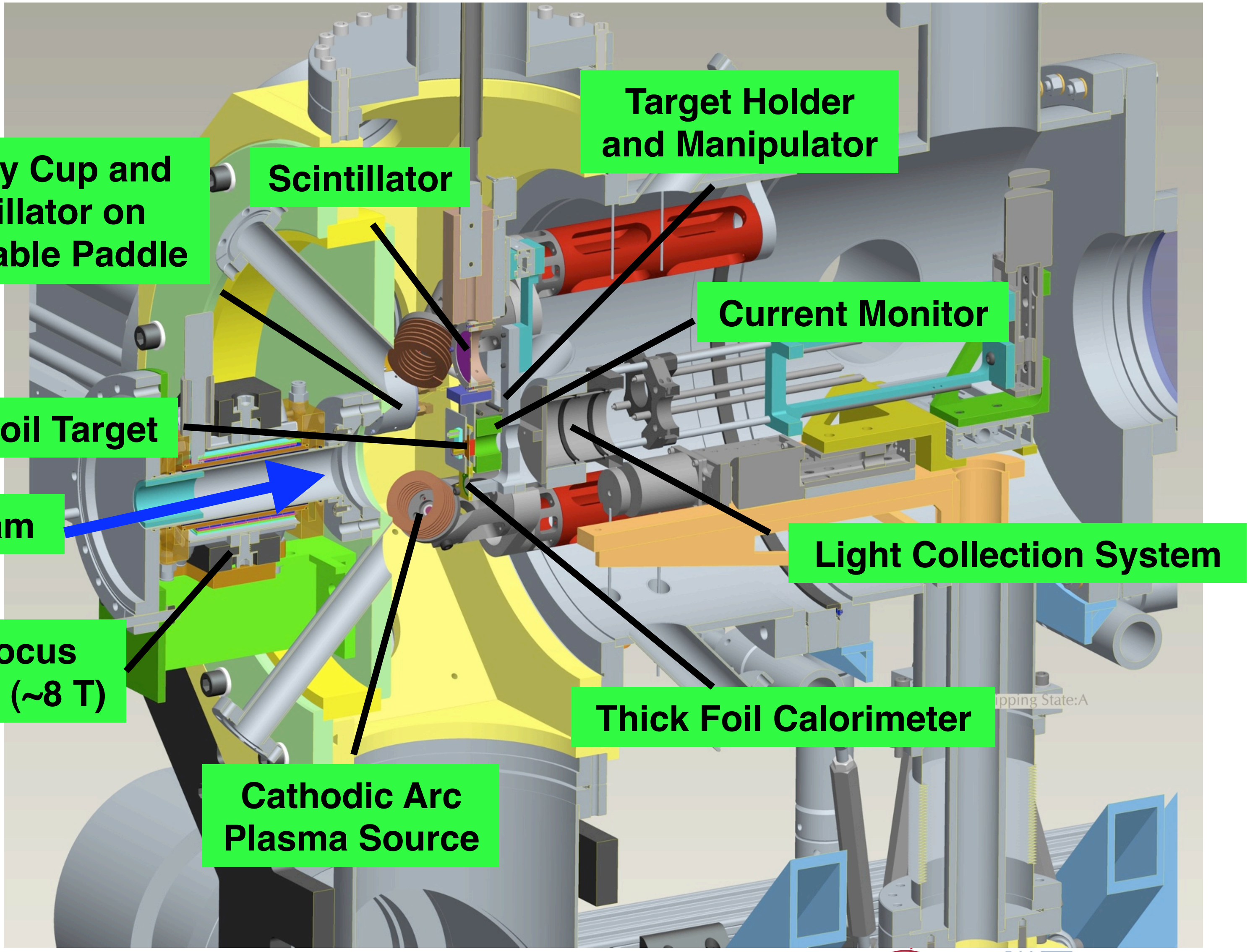


Beam

Beam transport system-level diagnostic

- Diagnostic signals acquired and analyzed on a shot-by-shot basis
- Integrated with ASP and Envelope models of machine behavior
  – Transverse beam offset
  – Average energy
  – Pulse length and temporal beam current profile
- Correlate Model with Measurements
  – Time-of-Flight and BPM offset measurements
- Provides feedback for accelerator cell timing, waveform fidelity, steering (‘golden orbits’ in beam-based steering)

Baseline target chamber instrumentation and diagnostics



Target Plane Beam Parameters

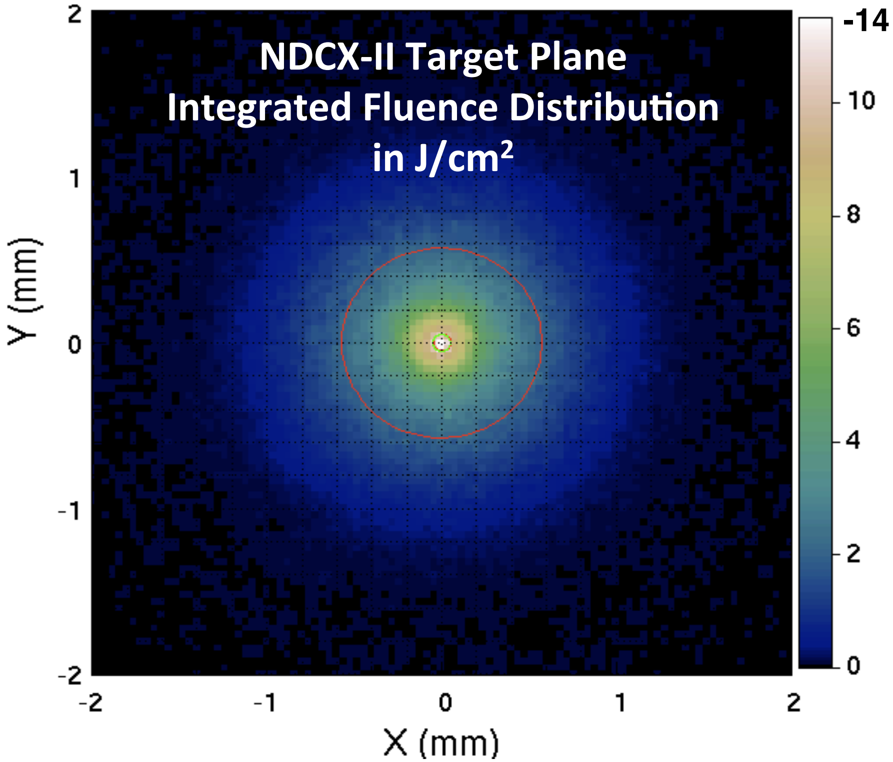
NDCX-II Target Plane Parameters	
Total Charge (nC)	55
Ion Kinetic Energy (MeV)	1.75
50% Fluence Focal Radius (mm)	0.6
Bunch Duration ($2^{1/2}$ FWHM) (ns)	0.4
Peak Current (A)	85
Peak Fluence (time integrated) (J/cm^2)	14.7
Fluence within 0.1mm aperture and duration (J/cm^2)	11

Fluences exceed surface damage thresholds.

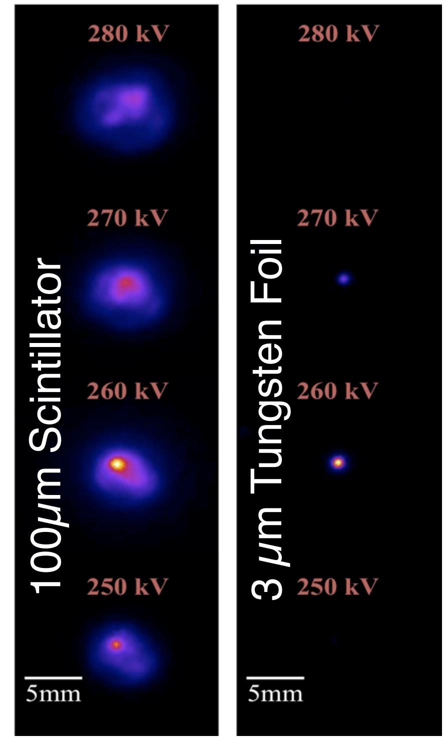
Thick tungsten foil calorimeter has successfully measured peak fluence in NDCX-I

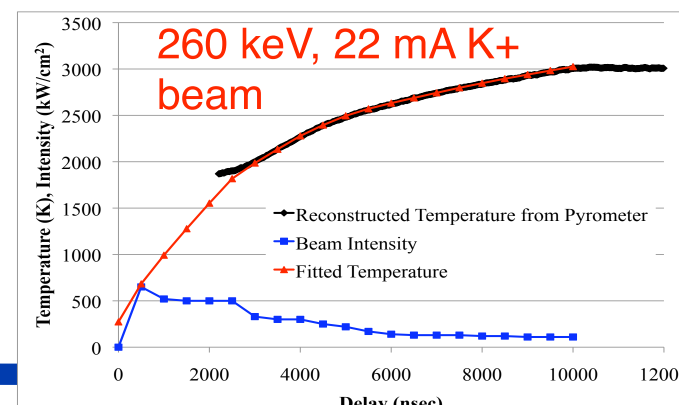
Thick tungsten foils are used in NDCX-I to calibrate peak intensity and fluence.

NDCX-II will have ~50-100X higher peak intensities. New calorimeter materials are needed to mitigate front surface blow-off



NDCX-I Results





Additional diagnostic facilities and future development for WDM and HEDP experimental capabilities

- Existing electrostatic energy analyzer can be deployed for energy spread measurements. 1-MeV (q=1), 2-MeV (q=2), 3-MeV (q=3)

- Accelerator beamline diagnostic cell upgrades:
  - Retractable solenoid – kinetic mounts maintain alignment
  - Insertable paddles with:
    - Scintillator – mirror
    - Slit - slit-cup pairs (both horizontal and vertical planes)

- Target chamber upgrades – achieving new beam fluence regimes

  Low-density targets (foams, aerogels, etc.) may permit volume heating without extensive surface blow-off

Roadmap from integration to WDM experiments

- **Integration Test**
  - – Low current and ‘pencil’ beam usage to study steering, check BPM calibration and sensitivity
  - – Noise levels will be measured and monitored
  - – Movable diagnostic box will characterize beam along beamline
  - – System diagnostics will determine timing and set points
- **Commissioning Phase 1**
  - – Full current injector: measure source aging effects on beam parameters
  - – Add any additional noise mitigation measures
  - – Fully characterize beam at pre-determined locations, cross-calibrate BPMs, measure beam jitter and corkscrew amplitudes
  - – Use final focus solenoid scans to provide insight on neutralized transport and final optics
  - – Integrate system diagnostics and BPM signals with machine model
- **WDM Experiments and User Operations**
  - – Improve beam fluence and fluence diagnostics
  - – Incorporate additional target diagnostics into machine performance upgrades
  - – Utilize data archiving and retrieval into enhanced model studies (eg. WARP)

Summary

Planned NDCX-II diagnostic capabilities will provide an extensive measurement platform to deliver optimized beams for WDM studies.

Baseline diagnostics will permit integration tests and basic commissioning of the full accelerator.

Intercepting diagnostic modules (insertible at first, then integrated later on) provide multiple means of interrogating the beam.

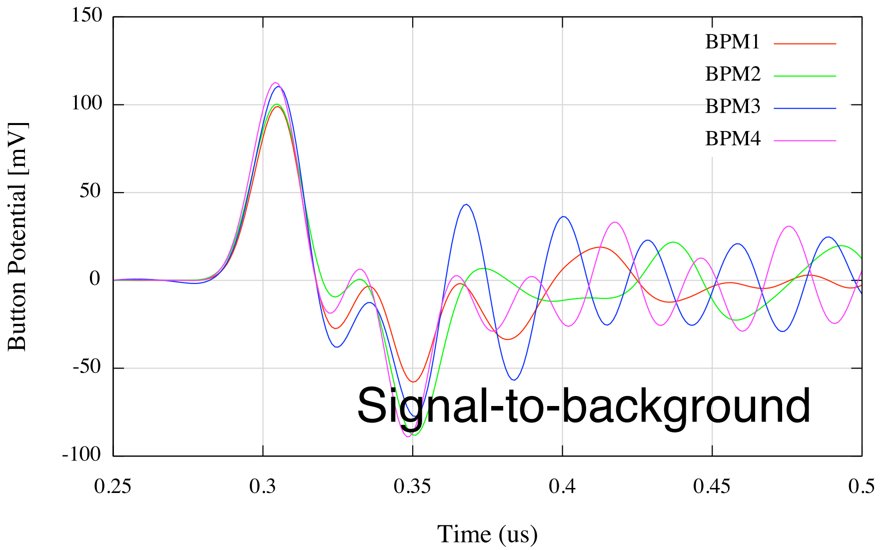
Integration with machine model will provide system-level performance diagnostics and indicate areas for improvement

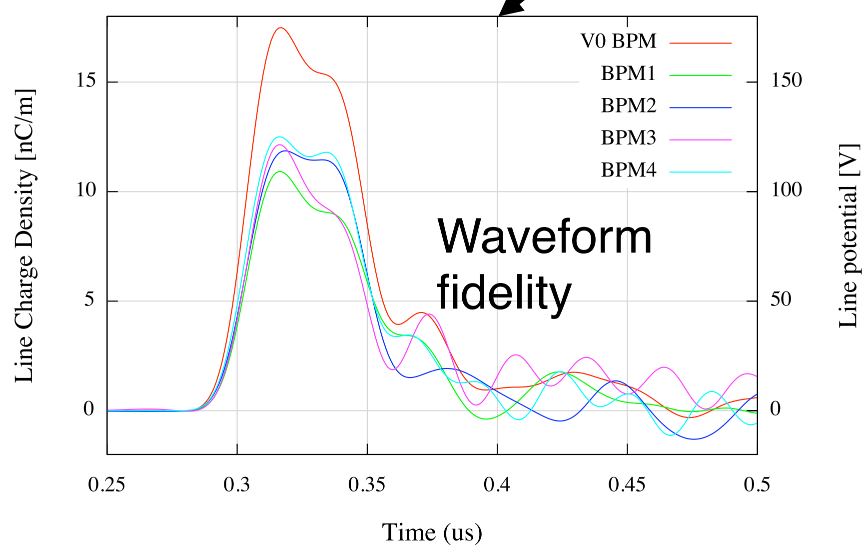
Target plane beam fluence will be improved by utilizing novel target diagnostics

Extra Slides

Capacitive BPM has been bench tested

Pulse Duration (ns)	Peak λbeam (nC/m)	Peak Electrode Potential (mV)	Velectrode/λbeam (mV/(nC/m))	Equivalent Risetime (ns)
30	3	25	8.33	19.1
30	6	50	8.33	19.1
30	12	100	8.33	19.1
30	17	150	8.82	18.0
100	1.3	10	7.69	20.6
100	3	25	8.33	19.1
100	6.5	55	8.46	18.8
300	0.6	5.2	8.67	18.3
300	1.3	10	7.69	20.6
300	3.5	27	7.71	20.6
300	7	55	7.86	20.2

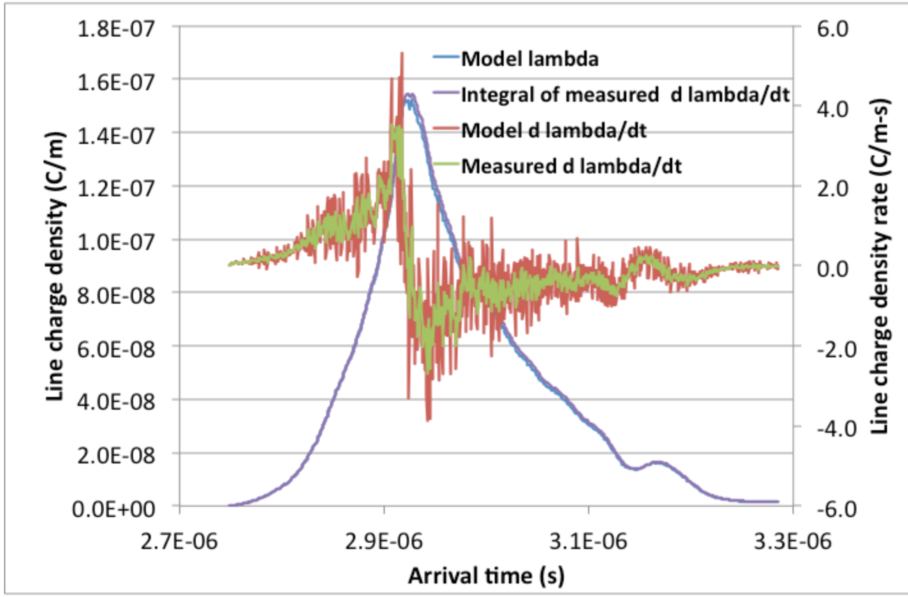


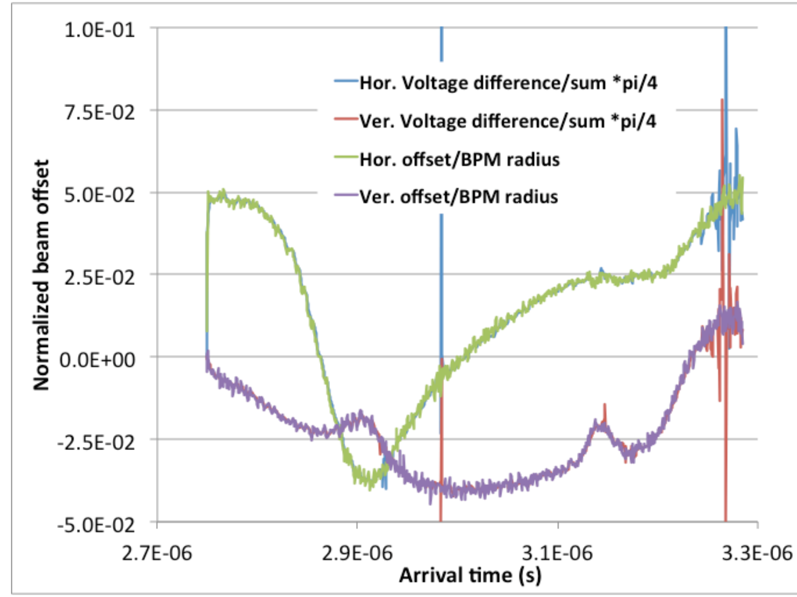


Additional benchtests will align the BPM to the magnetic axis and calibrate electrode Response to offsets.

WARP simulations will provide model-based sensitivity tests.

BPM sensitivity response to WARP model input (period #16)

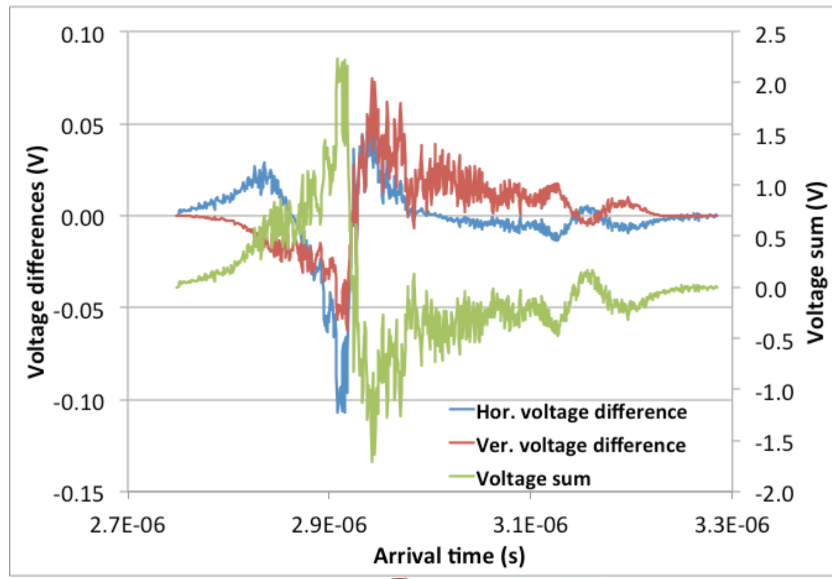




WARP model generates current, velocity, and transverse offset temporal profiles.

BPM circuit model then generates electrode signal voltage waveforms.

Analysis algorithms reconstruct ‘beam’ data.



Data Acquisition and Processing

Signal Chain:

BPM or fast signal generator
RF Signal Cable*
[Analog Processing – 500MHz Digitizer]*
Optical Fiber transport
Signal accumulation, post-processing, archiving

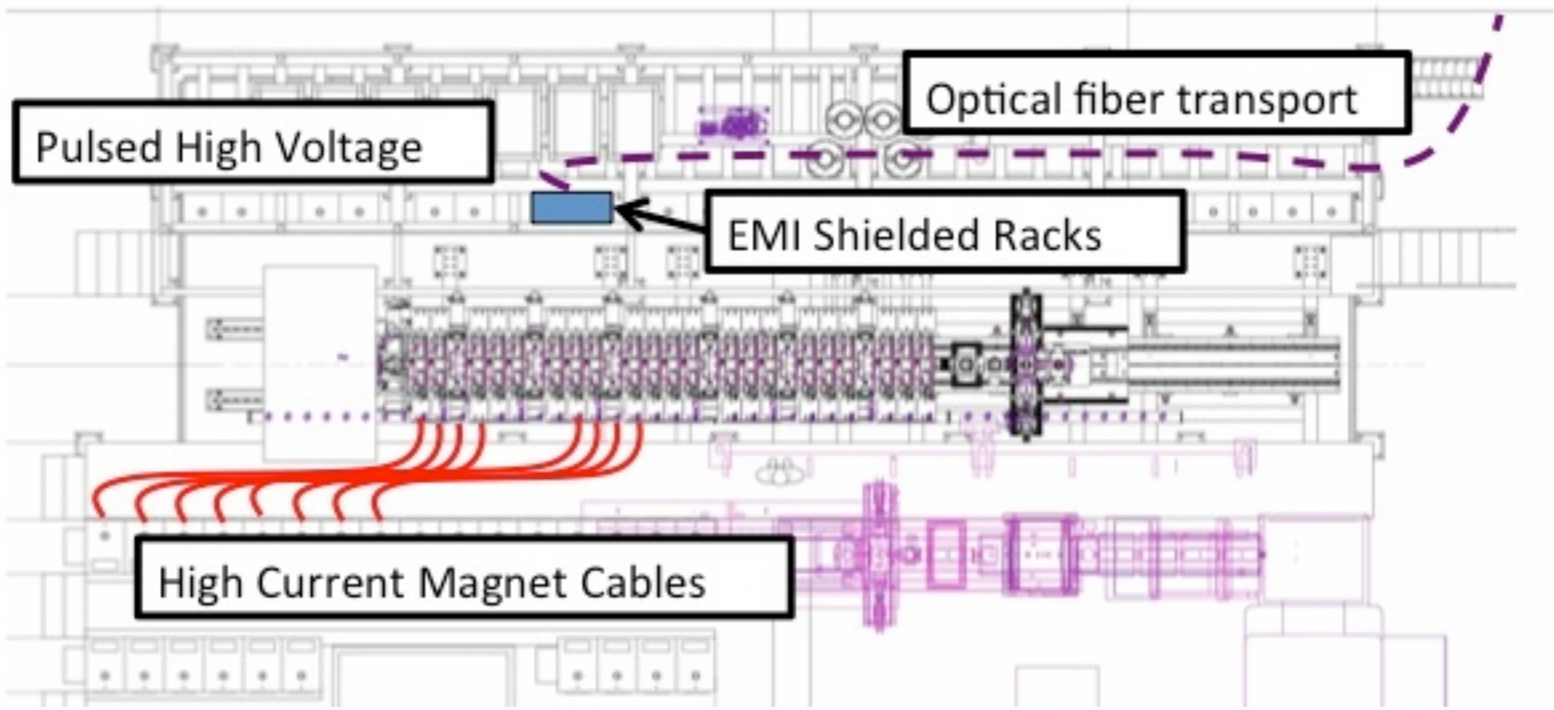
* EMI shielded enclosure

National Instruments PXI signal digitizer:

8-bit, 2GS/s, 500MHz digitizers for **fast** signals
Vertical sensitivity 0.1,0.2,0.5,1,2,5 $V_{pk\text{-}pk}$
BPMs, Faraday Cups

12-bit, 60MS/s, 35-60MHz for **slow** signals
Vertical sensitivity 0.05,0.2,1,6,30 $V_{pk\text{-}pk}$
Injector Voltage Waveform, Pulsed Solenoid Magnet, Pulsed Plasma

Noise mitigation relies on distance, EMI-shielded enclosures and optical isolation



- Diagnostic cables routed through steel tray enclosures to EMI shielded rack. Flexible conduit at both ends.
- Ground loops shielded with either inductive or capacitive isolation.
- Optical fiber transport to control room.